A Principal Components Analysis of Executive Processes: Exploring the Structure of Executive Functions using Neuropsychological Tests

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Contents:

Abstract

Whether executive system is a unified or separable structure is still a matter of debate. Using an individual differences approach, this study investigated the structure of five hypothesized executive functions (“Updating”, “Shifting,” “Inhibition”, “Dual-Tasking” and “Planning”) and their relationship to “Intelligence”. The separability of these executive functions was explored. Ten neuropsychological tests were administered to young and healthy participants (N =103). Correlations between tests that were expected to tap the same EF were low. Results of the Principal Components Analysis revealed nine components only 4 of which were clear enough to interpret in relation to previous literature. Overall results suggest some degree of separability of “Updating”, “Shifting” and “Dual-Tasking”, in addition to independence of all nine components from “Intelligence”. However there is some room for concern with regards to the overall reliability of these results (α = .487) and sample adequacy (KMO = .475).

Goals and actions that are organised across time are central to purposive behaviour. Even though the importance of such purposive behaviour is widely acknowledged, there is no unifying framework which accounts for how thoughts and actions are created, organised, carried out and monitored to achieve intended goals (Monsell, 1996). Rather the focus has been on the functioning of peripheral systems rather than the functioning of cognitive control (Bruce, 1996). Inability to explain how such cognitive control is obtained poses some problems in understanding cognition. Underspecified cognitive control processes inevitably led to an undesirable homunculus being introduced to theories of cognitive control (Baddeley, 1996).

Executive Functions (EF) are usually held synonymous with the idea of cognitive control and are described as the complex processes that organise thoughts and actions in a meaningful way to enable adaptive behaviour (Fuster, 2008; Jurado & Roselli, 2007). EFs are considered vital for pursuing a self-sufficient and independent life which is in agreement with societal structure (Lezak, Howieson & Loring, 2004).

Processes that are postulated to be a part of the executive processes are numerous. However it is generally agreed that executive abilities regulate behaviour by inhibiting irrelevant or inappropriate responses (Anderson & Levy, 2007), keeping attention on the task at hand (Baddeley, 1996); shifting task sets to allow flexible thinking and adaptable behaviour (Anderson, Levin & Jacobs, 2002); monitoring and updating of information flow through working memory (Salmon et al., 1996); enabling simultaneous performance of two tasks at the same time (Baddeley, 1996) and ensuring the creation and initiation of complex multi-step strategies to achieve a goal (Jurado & Roselli, 2007). These processes (and possibly more others) are thought to maintain the goal-directed nature of human behaviour.

Even though broad definitions of EFs are abound, they are far from specifying how cognitive control is achieved. Nor do they specify the underlying processes involved in executive functioning (Shallice, 2002). This lack of operationalized definitions creates difficulties in empirical research of cognitive control, as it makes it harder to create tasks or tests that measure the executive abilities (Rabbitt, 1997).

A very important question that is central to understanding how cognitive control is achieved, is related to the architecture of the EFs. It is still a matter of debate whether executive abilities all emerge from a single underlying construct (also referred to as theory of unity) or whether the EFs are distinct and independent components that work together to acheive cognitive control (also referred to as theory of diversity) (Jurado & Roselli, 2007). Both sides of this debate are supported by different lines of research that will be discussed in the next section.

The unity account of EFs states that there is a single process or mechanism that governs the executive functioning. However there are numerous ideas as to what constitutes the underlying construct. Salthouse (1993) proposed that cognitive aging originates from age related reductions in “processing speed”. However the definition of the processing speed and its relation to the specific executive functions is still considered to be somewhat ambiguous (Parkin & Java, 1999).

Another construct that is proposed as an underlying mechanism to executive abilities is intelligence (Jurado & Roselli, 2007) and is more central to the purpose of this study. The conventional accounts state that intelligence and executive abilities are unrelated constructs because some frontal lobe patients were reported to perform poorly on executive tests despite intact performance on intelligence tests, such as WAIS IQ (Shallice & Burgess, 1991). However, when patients who had preserved WAIS IQ scores were tested with a pure fluid intelligence measure such as Catell’s Culture Fair Test, marked impairments were observed (Duncan, Burgess & Emslie, 1995). These results suggest that fluid intelligence measures are related to executive functioning. Reasons for preserved WAIS IQ scores could be due to that some components of the test is highly related to crystallised knowledge.

Based on the relation between fluid intelligence and executive processes, Duncan, Emslie and Williams (1996) suggest that goal-neglect is a measurable construct that characterises frontal lobe deficits and it is very closely related Spearman’s g which can be displayed by fluid intelligence measures. Duncan et al. (1996) conclude that g should be the unifying factor behind the executive abilities. In a different study, it was further replicated that after accounting for the shared variance between EF tests and fluid intelligence, the correlations between the EF tests were no longer significant (Rabbit, 1997); supporting the idea of fluid intelligence being an underlying mechanism of EFs.

DeFrias, Dixon and Strauss (2006) also observed a one-factor solution in a confirmatory factor analysis study where two traditional and two relatively newer tests of EFs were administered. Even though a two-factor model (“Inhibition” and “Shifting”) was tested for; one factor solution emerged ("Executive Function") which was significantly correlated to fluid intelligence measures.

The debate for and against the unity or diversity account of executive control, is greatly influenced by the theoretical models such as the Working Memory Model (Baddeley & Hitch, 1974; Baddeley, 1996) and the Supervisory Attentional System (Norman & Shallice, 1980). Even though the early versions of these models display a more unified perspective of executive control; this was more likely due to the need to simplify complex constructs while dealing with more peripheral processes (Baddeley, 1996).

The roots of the diversity theory of executive system depend on the idea of identifying distinct EFs based on symptoms and neural networks involved in executive processes (Fuster, 2008). These separable components are usually thought to originate from PFC whose primary job is usually thought to mediate executive control (Miller, 2000).

Dissociable impairments that vary among the frontal lobe patients are suggested as an evidence for the separability of executive system (Godefroy, Cabaret, Petit-Chenal, Pruvo & Ruousseaux, 1999). Even though possible dissociations in executive processes could greatly impact our understanding of cognitive control, such suggestions should be interpreted with caution. One reason for this is that patient symptoms do not display one-to-one mapping to a region and there is great variability between the symptoms experienced and the extent of brain damage (Baddeley, 2002). Although patient studies provide insight into the understanding of cognitive control the complex brain-behaviour relationship is very salient for executive processes, making it hard to draw conclusions about the structure of EFs based solely on patient studies.

Fractionation of the executive processes are frequently shown by studies which take an individual differences approach. These studies utilise tasks or neuropsychological tests that are thought to tap different executive processes. A factor analysis can reveal common mechanisms underlying performances on various EF measures and show whether executive processes are separable. More importantly this approach can be applied to healthy participants (Chan, 2001) as well as a wide range of patient groups (Burgess, Alderman, Evans, Emslie & Wilson, 1998) and provides the opportunity to observe executive processes in young adults (Miyake, Friedman, Emerson, Witzki & Howerter, 2000) or age-related decline in executive abilities (Salthouse, 1996).

Many EFs have been observed as a result of these studies, such as “Intentionality” and “Executive Memory” (Burgess et al., 1998) or “Decision-making” (Verdejo-Garcia & Perez-Garcia, 2007). However for the purpose of this study, further discussion only focuses on the evidence for the fractionation of “Inhibition”, “Updating”, “Shifting”, “Planning” and “Dual-Tasking” since they are examined in this study. In addition to briefly reviewing these EFs, tests which are administered in this study to tap each of the EFs are introduced.

“Shifting”

Also referred to as set shifting (Monsel, 1996) or rerouting (Shimamura, 2002), “Shifting” is defined as the ability to switch between task sets or action schemas to allow flexibility in thoughts and actions according to environmental demands (Rogers & Monsell, 1995).

Frontal lobe patients may display impairments in set-shifting which result in perseverative responses in rule attainment tasks such as Wisconsin Card Sorting Test (WCST, Stuss & Benson, 1984). However, impaired set-shifting is not specific to frontal lobe patients (e.g. Parkinson’s disease, PD, Cronin-Golomb, Corkin & Growdon, 1994) although Owen et al. (1993) suggest that shifting deficits observed in frontal lobe patients and PD patients could have different origins, as a result of impairments to different cognitive processes. Shifting abilities have also been linked to frontal lobes in healthy participants during switching tasks (Moulden et al. 1998); although multiple regions are likely to be in charge of various aspects of cognitive control during these tasks (Braver, Reynolds & Donaldson, 2003; Dove, Pollma, Schubert, Wiggins, & vonCramon, 2000).

Fractionation of “Shifting” is very frequently observed in individual differences studies (Miyake et al. 2000; Verdejo-Garcia & Perez-Garcia, 2007), commonly assessed with tasks that involve switching between different task sets and response sets, such as the WCST. In this study Trail Making Test (Reitan & Wolfson, 1985) and Brixton Spatial Anticipation Test (Burgess & Shallice,1997) were used as measures of “Shifting”. Trail Making Test, is regarded as a well-established clinical tool in frontal damage screenings (Parkin & Java, 1999). The Brixton Test was developed as a measure of non-verbal rule-attainment task, thought to be sensitive for frontal impairments (Burgess & Shallice, 1997; Strauss, Sherman & Spreen, 2006).

Brixton Test was one of the tests administered by DeFrias et al. (2006) in a factor analysis which loaded on one single factor with all the other tests. Therefore it is also important to see the relationship of this test with the other measures used in this study.

"Inhibition"

The label of Inhibition is frequently used to express different levels of processes and is usually poorly defined. In this study, the term "Inhibition" is used for the concept of overriding or inhibiting a pre-potent or more dominant cognitive process or response (MacLeod, 2007). Inhibition is usually regarded as an important process in cognitive control (Garavan, Ross, Murphy, Roche & Stein, 2002) and have been frequently observed as an independent factor in studies reviewed above (Miyake et al., 2000; Burgess et al., 1996; Chan, 2001)

Known to be associated to frontal lobes (Adleman et al. 2002), the Stroop task is a traditional method with which inhibitory abilities are investigated; because the inhibition condition of the test requires participants to inhibit the dominant response (reading) and perform the less automatic response (ink naming).

In this study, one of the measures that is hypothesized to tap "Inhibition" is the Colour-Word Interference Test (D-KEFS, Delis, Kaplan & Kramer, 2001), which can be considered as a Stroop Test variant. Even though the Stroop tests are sometimes regarded to reflect perceptual filtering; the ability to inhibit a very strong response (word reading) is considered to be more reflective of inhibitory abilities in this study (Redick, Heitz & Engle, 2007).

The second measure of "inhibition" is the Hayling Sentence Completion Test (Burgess & Shallice, 1997), which requires participants to inhibit appropriate words and respond with unrelated words to sentences which have their last words missing. This test is thought to be sensitive to frontal disturbances (Strauss, Sherman & Spreen, 2006).

"Updating"

Usually considered within the same framework of Working Memory (Salmon et al., 1996) "updating" refers to encoding incoming information, monitoring and manipulating it; usually to result in a different string of information from the original (Morris & Jones, 1990).

It is important to differentiate between updating processes and storage of information in memory. Whereas the latter implies holding a piece of information on-line in memory, "updating" is more of a dynamic task which requires working with current information. This differentiation is shown via neuroimaging studies which link "updating" with dorsolateral regions; whereas storage of information seems to activate pre-motor cortex and parietal cortex (Jonides & Smith, 1997).

Fractionation of Updating was demonstrated in literature with memory tasks that involve monitoring of information (Miyake et al. 2000; Verdejo-Garcia & Perez-Garcia, 2007). In addition, increased severity of drug abuse was found to correlate with decreased performances on "Updating" measures; but not with other EFs observed in the study (Verdejo-Garcia & Perez-Garcia, 2007).

Digits Backward and Letter number Sequencing Tests (both from WMS-III, The Psychological Corporation, 1997, 2002) were administered as measures of "Updating". Both tasks involve monitoring strings of information that needs to be manipulated in different ways to reach a pre-determined, correct order.

"Dual-Task"

Dual-tasking (DT) is considered to be a convenient way of investigating executive processes as it uses the framework of Working Memory Model (Baddeley & Hitch, 1974) to identify the relationship between executive system and the slave-systems (Baddeley & Della Sala, 1996; Baddeley, 1996). It can be described as the ability to orchestrate two simultaneously performed tasks (Baddeley, 1996). This orchestration is thought to reflect the executive abilities (Baddeley & Della Sala, 1996) and is linked to frontal lobes (D'Esposito et al. 1995).

DT impairments are seen in many patient populations. For example Baddeley et al. (1991) showed Alzheimer's Disease patients to have a marked continuous decline in dual-tasking of a tracking task and a digit recall task over a 6 months period, despite intact single-task performances over this period of time. Similar results are also observed for different patient groups such as Parkinson's Disease or Traumatic Brain Injury (Dalrymple-Alford, 1994; Hartman et al. 1992).

Previously, age-related decline in cognitive tasks was associated with decline in processing speed (Bors & Forbin, 1995). It could be argued that decreased DT abilities observed in patient groups is just related to this decline. However, healthy aging participants do not display any impairment in DT abilities; therefore DT is not related to any decline over processing-speed (Baddeley, 1996).

The possibility of DT being a separable EF was suggested by Baddeley (1996), also supported by the structural equation modelling analysis in Miyake et al. (2000) where DT was not observed to load on any of the previously determined EFs (“Inhibition”, “Updating” and “Switching”). In this study, a pencil-and-paper format test was used, developed by Della Sala, Foley, Beschin, Allerhand & Logie (2010).

“Planning”

The last EF to be investigated in this study is “Planning” which can be described as the ability to select appropriate actions sets or strategies in the required temporal organisation to achieve a goal (Ward, 2005) usually in a novel and complex situation (Jurado & Roselli, 2007). Lower-order planning, which refers to the planning and execution of automatized/overlearned behaviour patterns is not discussed here; since it higher order planning seems to involve more executive component (Ward, 2005). Disorganised behaviour and inability plan is frequently associated to frontal lobe damage (Shallice & Burgess, 1991). Impairments to SAS functioning was put forward as a possible reason for the observed deficits, which leave the overlearned responses intact and unimpaired (Shallice, 1982).

Tower tests, such as Tower of London or Tower of Hanoi are administered as traditional measures of planning. These tests which require participants to reorder disks to achieve a model outcome; usually within particular rules such as time or move limits, is strongly linked to multiple regions in PFC (Baker et al., 1996)

Similarly, Morris, Kotitsa and Braham (2005) observed a left-right frontal dissociation among frontal lobe damaged patients using Tower of London Test in an fMRI study, where the left frontal patients were only found to be impaired on goal-sub goal conflicts (performing correct moves that do not seem to contribute the end goal) whereas the right frontal lobe patients were more affected by increasing tower complexity. These results (Morris et al., 2005; Baker et al., 1996) could suggest that a co-operative network is needed for planning abilities measured by the Tower tests, instead of a single region being responsible for the processes.

Even though planning abilities are at times postulated to involve executive processes, not much is known as to the details of exactly what “planning” involves (Morris et al. 2005). The degree to which “planning” abilities involve executive processes can be questioned, since the novelty of a situation and preferences for one action over another could play an important role in relation to one’s current planning (Burgess, Simons, Coates & Channon, 2005) and “planning” may be far from being a unitary construct (Philips, MacLeod & Kliegel, 2005).

In this study, “planning” was investigated using a Tower test (D-KEFS; Delis, Kaplan & Kramer, 2001) and Zoo Map Test (BADS, Wilson et al. 1996). The Zoo Map test is considered to be a more ecologically valid measure of planning abilities and is frequently utilised as a clinical tool when screening for frontal damage (Chamberlain, 2003).

<u>The central goals of the current study:</u>

Using an exploratory factor analysis, the current study takes an individual differences approach to investigate the structure of these five EFs in relation to neuropsychological test performance of young and healthy adults. Unlike the Confirmatory Factor Analysis, the EFA does not fit pre-conceived model for the data. Rather, the best factor model is decided based on preliminary analysis and factor solutions. This is advantageous from the perspective of this study since neuropsychological tests are administered.

Task impurity, which refers to the possibility of a task creating workload for peripheral processes in addition to the executive processes (Rabbitt, 1997), is an important problem for neuropsychological tests. It is known that these tests, which are frequently administered in clinical settings, may be more susceptible to suffer from task impurity (Cripe, 1996). Moreover, it has been suggested that the tests or tasks that are hypothesized to obtain a measure of EFs, usually have low process-behaviour correspondence (Burgess, 1997). This is to say that executive processes may be difficult to capture with some measures as they do not always have overt reflection to behaviour. Since the tests that are administered might not reflect their hypothesized EF processes to the fullest extent, an exploratory approach could reveal more about the nature of the tests despite harder interpretations of the results.

In addition, the relationship between the hypothesized EFs and Intelligence was also of interest to this study. Since the unity theory of executive system suggests fluid intelligence to be the underlying process of executive system, it is important to investigate how intelligence measures relate to the hypothesized EFs.

Studies which explore the relationship between EFs and Intelligence display conflicting results. In one study, only “Updating” correlated with both Fluid and Crystallised intelligence measures of WAIS IQ (Friedman et al. 2006). The lack of correlation between “Shifting” and “Inhibition” to intelligence measures were attributed to the lack of sensitivity of the intelligence measures used to the specific EFs. In another study (Unsworth et al. 2009), all four of the emerging EF components were correlated to the gf (measured with Raven’s Progressive Matrices and Number Series).

Even though the nature of the current study is exploratory, based on previous evidence, a separable five factor solution is expected to emerge. The frequency with which “Inhibition”, “Updating” and “Switching” are observed as separate components throughout the literature is a strong evidence for the fractionability of these three measures. There is also good evidence for the separability of “Dual Tasking”. “Planning” on the other hand is a lot more difficult to interpret since it is less pure as a construct and the tasks used to tap this functions is a lot more likely to involve other non-executive processes. The five executive processes are also expected to be separable from the intelligence factors.

Some degree of correlation was observed with neuropsychological tests, which was previously interpreted to be due to fluid intelligence (Rabbit, 1997). However, Miyake et al. (2000) observed correlations between factor solutions which were not accounted for by any measures of intelligence. In this study, no directionality is assumed in relation to within-factor correlations since the degree to which the test measures correlate is not known.

Method

Participants

106 healthy and non-dyslexic participants who were between the ages of 18-30 and had good fluency in English, took part in the study. The recruitment was done over a advert via the SAGE website. Each participant was allocated a single two hour session however the time taken to complete a session varied according to the individuals. Payment

amount changed according to the time taken to complete the whole session; one full hour being granted £6; one and a half hours being granted £9 and two hours in £12. Since participants almost never learned the exact amount of money they would earn until the end of the study, it is very unlikely that payment acted as an incentive to longer testing sessions.

Materials

In each session, ten tests were administered in total. Multiple measures were used for each EF (excluding "Dual-Tasking") in order to try to reduce the problem of task impurity (Miyake et al., 2001, as cited in Strauss, Sherman & Spreen 2006).
Nine of these test were administered as a measure of one of the five hypothesized EFs: "Inhibition", "Switching", "Planning", "Dual-Tasking" and "Updating". The remaining test was a two-subtest version intelligence test to obtain crystallised ("gc") and fluid ("gf") intelligence measures. All of the tests were administered in paper-and-pencil format. The reaction time (RT) data were recorded with a stop-watch. The next section gives more information on the tests and the dependent variables obtained for each measure.

The tests used as a measure of "Planning":

Zoo Map Test (BADS, Wilson et al. 1996): The Zoo Map Test was designed as a measure of the ability to create and carry out a plan. The test requires participants to plan a route through the map of a zoo following the task rules related to zoo sites and roads. Successful completion of the test relies on the ability to pre-plan the route. Two RTs were collected: Plan RT (which is the time elapsed from when a pen was given to the participant until when the participant expressed being ready to draw) and an Overall RT (which covers the Plan RT until the participant finishes drawing the route).Participants were allowed to take as much time as they needed before starting to draw.

Planned routes were scored such that each correct site that was visited in the correct sequence received 1 points. Any rule violations resulted in 1 point being deducted from the overall score. The maximum score that participants could achieve was 8.

Tower Test (D-KEFS, Delis, Kaplan & Kramer, 2001): This test presents participants with a wooden peg and five wooden disks of various sizes. The participant's task is to move the disks to copy a specified model which is presented on paper. There are nine trials which models of increase in complexity. The tower complexity is determined by the number of disks to be moved per trial, easiest trials involving two and hardest trials involving 5 disks. At the start of each trial, the disks are placed on the peg in a starting position by the administrator and the participants are instructed to use only the disks that were on the peg.

The main aim of participants, is to make the model tower using as few number of moves as possible. Participants' towers were scored according the number of moves made to achieve the end result, as instructed in scoring manual. The total Achievement Score which is the combined scores of all nine towers, was entered into data analysis. Maximum score a participant can get is 30.

Even though there is a time limit per trial, participants in this study were allowed slightly longer time as long as their actions seemed purposive. This was done since the participants were expected to be healthy and capable of forming and carrying out plans. The time taken to complete each tower was recorded from the moment when the participant saw the model tower, until when the last disk was placed on the peg for a given tower. Combined trial scores were entered into data analysis.

Tests used as a measure of "updating":

Digits Backwards (WMS-III, The Psychological Corporation, 1997, 2002): This test is composed of 14 number sequences of increasing length, read aloud by the administrator one by one. Participants task is to listen and repeat each sequence in reverse order. For example if participants heard the sequence of 1-4-3, the correct backward order would be, 3-4-1. The test starts with relatively easier two digit sequences and increase up to eight digit sequences.

Successful completion of each trial depends on the ability to keep each sequence in working memory for the duration of a trial and to manipulate the order of the sequence to obtain a reversed sequence. For an answer to be correct, participants had to say the correct numbers in the required backward order. All the answers were verbatim and correct answers were given 1 points. Maximum score that participants could obtain was thus 14.

Letter-Number Sequencing (WMS-III, The Psychological Corporation, 1997, 2002): This test is composed of 21 mixed letter and number sequences, read aloud one at a time by the administrator. The participant's task is to listen to and reorder each sequence so that the numbers are put in ascending order first, followed by the letters put in alphabetical order. For example if the participant heard "8-D-6-G-1" the correct answer would be "1-6-8-D-G". The sequences started with 2-items (one digit, one letter) and increased up to 8-item sequences (four digits, four letters). Three trials were administered for each item-sequence. The correct letters and numbers have to be in the right order for an answer to be given 1 points. Scores for all trials are combined to be used in analyses.

Tests used as a measure of "shifting":

Brixton Spatial Anticipation Test (Burgess & Shallice, 1997).This test is a rule attainment task where the participant's task is to figure out the rules that govern the movement of a blue circle throughout the test booklet. Each page of the booklet consists of ten circles fitted in a rectangular box on two rows (numbered accordingly from 1-6 in the first row and 7-10 in the second). On each page one of the circles is filled in blue colour which moves across the 9 empty circles every time a page is turned. The movement has an unpredictable pattern which changes without warning.

The participant's task is to work out the pattern of the blue circle and to predict where it will be on the next page. The first trial is not scored since it is a guess. Each wrong answer is given 1 point, so a higher score indicates worse performance on the test. Total score is included in the analysis.

Trail Making Test (Reitan & Wolfson, 1985): The test which is in the public domain (Lezak et al, 2004) has two parts. In part A participants connect numbered circles with a pen as fast as possible, following the ascending numerical order (1-2-3-4 and so on). In Part B, half of the circles are numbered from 1 to 13 and the other half of the circles contain letters from A to L. The participant's task is to connect the circles, alternating between number category and letter category simultaneously (1-A-2-B-3-C and so on). Thus, to be able to complete the test, participants need to shift from one category to another. RT data is collected for both parts. Moreover to obtain a purer measure of shifting abilities, B-A (Lezak et al. 2004) and B/A (Lamberty et al. 1994) measures are also calculated and included in analyses.

Tests used as a measure of "inhibition":

Hayling Sentence Completion Test (Burgess & Shallice, 1997): This test consists of two sections. The first section (Hayling A) includes 15 sentences with their last words missing. For each sentence, participants are asked to come up with a word that completes the sentence as fast as possible. RT data is collected from when the examiner finishes reading the sentence until when the participant gives an answer. All RT data are combined to obtain a measure of this part.

The second section (Hayling B) is similar and participants hear another set of 15 sentences. This time participants are asked to come up with a word that is completely unrelated and irrelevant to the sentence, as quickly as possible. Therefore this section measures inhibition. RT's for all 15 sentences were taken in the same way as in the first section. The participant's answers were noted down to later check for the relevance of the word to the sentence. As the participants were healthy adults, there was less tendency to reply with a still relevant word. For this reason the error data were not entered in the final analysis.

Colour-Word Interference Test (D-KEFS; Delis, Kaplan & Kramer, 2001): This test is a Stroop test, however contains four different conditions, only three of which were administered in this study. The first condition is the colour naming where participants name the colour of 50 coloured squares. The colours were either red, green or blue. The second condition was word reading where the participant reads 50 colour words printed in black ink printed in black ink. The final condition contains colour words printed in different ink colour and the participant aims to name the ink colour of 50 words without reading.

10 practice trials were provided at the start of each condition. For all sections participants are asked to be as quick as possible. RT data and errors made were noted down to be included in the final analysis.

Only one test was administered for “Dual-Tasking”:

Dual-Task: Developed by Della Sala et al. (2010) this test uses a digit-recall task and a tracking task to obtain a measure of dual-task ability. Each task is first performed separately to asses single-task performance; followed by simultaneous performance of both tasks for the assessment of dual-tasking.

Prior to the digit recall task, a digit span test is administered to identify the maximum digit capacity of participants. The participant hears a digit sequence at a time which needs to be repeated back. The length of the sequence is increased by a digit every time a participant can successfully recall three out of five trials per sequence length. The last digit sequence in which three out of five trials were recalled correctly is a participants digit span.

After establishing the digit span for each participant, the digit recall task is administered where the participant hear digit sequences that are always as long as their digit span. The task is to repeat back as many sequences as possible in one minute. Single digit recall performance is calculated according to total number of digits recalled correctly in its correct position in a sequence.

The tracking task consisted of drawing a single continuous line through empty 328 circles. The circles followed a convoluted path on a sheet of A3 paper. Prior to performing the actual task, participants are given a smaller sheet with 17 circles to practice. The tracking performance is scored based on the number of circles crossed in one minute.

After completing both tasks separately, participants perform both the tasks simultaneously to the best of their performance in one minute. Scoring is done according to the same criteria as in single-task conditions. The following formula is used to calculate the change in participants performance from when they perform the digit recall on its own to when they do it in dual-task condition. This results in an overall Digit Recall performance (%).

$$\textit{Digit Recall}\ (\%) = 100 - \left\{ \frac{\left(\text{Digit Recall}_{(\text{Single Task})} - \text{Digit Recall}_{(\text{Dual Task})}\right) \times 100}{\text{Digit Recall}_{(\text{Single Task})}} \right\}$$

The change in tracking performance from the tracking task on its own to tracking task in dual-task condition is also calculated in a similar manner to obtain an overall Tracking performance (%).

$$Tracking\ (\%) = 100 - \left\{ \frac{\left(\mathbf{Tracking}_{(\mathbf{Single\ Task})} - \mathbf{Tracking}_{(\mathbf{Dual\ Task})}\right) \times 100}{\mathbf{Tracking}_{(\mathbf{Single\ Task})}} \right\}$$

An average of the overall Digit Recall performance and overall Tracking performance is obtained:

$$Overall\ Dual\ Task\ (\%) = \frac{Digit\ Recall\ (\%) + Tracking\ (\%)}{2}$$

<u>The following tests were administered as measures of “gf” and “gc”:</u>

Wechsler Adult Scale of Intelligence (WASI; Psychological Corporation, 1999): Two-subtest version of WASI was administered where the Vocabulary test was used as a measure of “Gc” and the Matrix Reasoning test as a measure of “Gf”.

The Vocabulary subtest requires participants to define 42 words of increasing complexity. The participant’s responses are noted down to be scored later according to the scoring manual, which includes keywords or phrases that describe the target word at different degrees. The best and most inclusive definition receives 2 points; a relatively less inclusive but still correct definition receives 1 points and an incorrect word receives 0 points. The scores obtained for all words are combined to obtain a total score out of 80.

The Matrix Reasoning subtest is a non-verbal reasoning test where participants try to figure out the rule that governs a pattern. In each trial, there are colourful shapes where one part of the shapes are covered with a question mark. The participant’s task is to look at a choice of 5 answers and decide which one of them best fit in the pattern seen on a trial. Answer choices in each trial are numbered from 1 to 5 and participants express their response by naming a number out loud. Two practice trials are administered which were not scored. Each correct response is given 1 points and maximum score that can be achieved is 35 points.

General Procedure

The order in which tasks were administered was fixed across all participants to prevent any confounding order effects. After reading the participant information sheet and signing the consent form, the tests were administered following this order : Dual Task, Vocabulary Test, Matrix Reasoning Test, Digits Backwards, Letter Number Sequencing, Trail Making Test, Colour-Word Interference Test, Towers Test, Zoo Map, Hayling and Brixton Spatial Anticipation Test.

Results

First, the collected data was screened for outliers. One participant's data (participant #92) was removed as he was colour-blind and had difficulty completing the Colour-Word Interference Test (CWI). Two more participants (#38 and #79) were also excluded from the data analysis due to extremely low scores in Tracking and Digit Recall tasks in Dual-Tasking respectively. The mean age for the remaining 103 participants (of which 58 was female and 48 male) was 22.87 ($SD = 2.67$). Table 1 displays the descriptive statistics results for all of the variables.

Before performing any further analysis the data was checked for normality using the Kolmogorov-Smirnov Test which revealed deviation from normality for majority of the variables. However considering the sensitivity of this test to larger data sets the normality was further investigated by computing the Z scores for skewness and kurtosis and plotting histograms and scatter plots for each variable. The Zoo Map Scores were significantly negatively skewed due to an apparent ceiling effect of the test. Error scores for the Colour-Word Interference test were also significantly positively skewed due to small number of errors made.

To overcome the problem of non-normality, the Zoo Map Scores were reversed and all of the variables were transformed using a Log ($X_i + 1$) transformation. The reason for performing a +1 transformation was the presence of 0 scores in some variables (such as Hayling A). After the transformation, variables were plotted once more to ensure normality. Results of the plotted graphs displayed normal distributions after transformation.

Table 1
Descriptive Statistics for all of the Dependent Variables (N = 103)

Variables	Mean (SD)	Range
Digit Recall (%)	97.99 (18.93)	57.89 -171.44
Tracking (%)	99.3 (12.58)	66.36 - 128.42
Dual Task Overall (%)	98.6 (10.74)	65.47-134.94
Digit Span	7.01 (1.176)	04 - 10
Matrix Reasoning	28.67 (2.99)	21 - 34
Vocabulary	67.44 (6.42)	45 - 79
Digits Backwards	8.90 (2.2)	4 - 14
Letter-No Sequencing	12.7 (2.43)	6 - 19
Trails A	19.26 (5.085)	8 - 33
Trails B	46.83 (16.239)	18 - 132
Trails B-A	27.57 (14.719)	7 - 103
Trails B/A	2.49 (0.74)	1.25 - 4.55
CWI- Naming Error	0.37 (0.727)	0 - 5
CWI- Naming (RT)	26.66 (5.345)	19 - 51
CWI- Reading Error	0.26 (0.523)	0 - 3
CWI- Reading (RT)	19.47 (2.29)	14 - 28
CWI- Inhibition Error	1.12 (1.45)	0 - 8
CWI- Inhibition (RT)	44.48 (9.57)	21 - 86
Towers (RT)	416.8 (128.02)	160 - 756
Towers Score	19.79 (3.345)	10-29
Zoo Map Scores	6.81 (2.17)	1 - 8
Zoo Map (Overall RT)	153.69 (86.93)	29 - 444
Zoo Map (Plan RT)	107.01 (78.152)	6 - 390
Hayling A	4.11 (4.47)	0 - 33
Hayling B	13.03 (11.82)	0 - 60
Brixton	9.69 (3.97)	2 - 22

Note. CWI refers to Colour Word Interference Test.
All values are written to two decimal places.

The error variables in the Colour-Word Interference Test (CWI) were excluded from the analysis. This is because majority of the participants did not make any errors in any of the conditions; therefore the data did not provide much information about inhibition processes. The RT data for the CWI test should be more representative of inhibitory processes.

Correlations among 23 variables were investigated using a Pearson's Correlation. These values can be viewed in the Appendix. Examining the pattern of correlations revealed that the tests which were hypothesized to tap the "Updating" were significantly correlated: There were significant positive correlations between Digits Backward and Letter-No. Sequencing scores, $r = .493$, $p < .01$; Digits Backward and Digit Span scores, $r = .410$, $p < .01$; Digit Span and Letter-No. Sequencing scores, $r = .446$, $p < .01$. Apart from "Updating" measures, none of the other tests which were hypothesized to tap the same EF correlated.

Not surprisingly, significant correlations were observed between the variables that were obtained from the same tests. According to this, Zoo Map Overall RT was positively correlated to Planning RT, $r = .617$, $p < .01$; Hayling A scores were positively correlated to Hayling B scores, $r = .322$, $p < .01$. CWI Inhibition RT was correlated to both Naming RT ($r = .617$, $p < .01$) and Reading RT ($r = .389$, $p < .01$). Naming RT and Reading RT were also positively correlated, $r = .671$, $p < .01$. Trails A RT was significantly correlated to Trails B ($r = .519$, $p < .01$) although it was negatively correlated to Trails B/A ratio ($r = -.352$, $p < .01$). No relationship between Trails A and Trails B-A measures were observed. On the other hand, Trails B RT was significantly positively correlated to both Trails B-A measure ($r = .894$, $p < .01$) and B/A ratio ($r = .608$, $p < .01$). Towers Score was found to be negatively correlated to Towers RT, $r = .411$, $p < 0.01$; which suggest that higher scores were associated with shorter overall RT's. The Overall Dual Tasking measures were also positively correlated to both Digit Recall scores ($r = .793$, $p < .01$) and Tracking scores ($r = .493$, $p < .01$). No correlations between Tracking and Digit Recall measures were observed. Matrix Reasoning and Vocabulary Test were also positively correlated $r = .196$, $p < .05$.

Vocabulary Test was correlated to many of the variables. There was a positive correlation between the Vocabulary Test and Letter Number Sequencing, ($r = .230$, $p < .01$) and Towers Scores ($r = .199$, $p < .05$). Negative correlations were observed between the Vocabulary test to Trails B ($r = -.251$, $p < .05$), Trails B-A ($r = -.272$, $p < .01$) and Trails B/A ($r = -.226$, $p < .05$) and CWI Reading RT ($r = -.272$, $p < .01$). Matrix Reasoning subtest was negatively correlated to Trails A RT, $r = -.201$, $p < .05$. The lack of correlation between the tests that were hypothesized to tap the same EFs and strong within-test variable correlations suggest that more components (than the expected 5 component solution) can be observed.

An exploratory factor analysis was performed using a Principal Components Analysis (PCA). The reason for choosing PCA over Principal Axis (PA) factoring was that (possibly due to smaller sample size) the communality of one variable exceeded the value of 1 after the extraction; therefore the PA was not suitable for the this study. However both PCA and PA are known to result in similar factor solutions, since both of them try to maximize the variances extracted in the analysis (Field, 2005; Tabachnick & Fidell, 1996). Therefore a PCA analysis was performed for 23 variables.

Table 2

KMO values and Communalities after extraction.

Variables	KMO	Extracted Communalities
Digit Recall	0.261	0.942
Tracking	0.148	0.829
Dual-Task	0.31	0.976
Digit Span	0.663	0.674
Matrix Reasoning	0.451	0.659
Vocabulary	0.641	0.595
Digits Backward	0.605	0.715
Letter No Sequencing	0.529	0.742
Trails A	0.289	0.860
Trails B	0.492	0.921
Trails B-A	0.438	0.937
Trails B/A	0.596	0.838
CWI Naming (RT)	0.6	0.753
CWI Reading (RT)	0.743	0.701
CWI Inhibition (RT)	0.696	0.673
Towers (RT)	0.548	0.654
Towers Score	0.616	0.418
Zoo Map Scores	0.508	0.931
Zoo Map (Overall RT)	0.515	0.909
Zoo Map (Plan RT)	0.502	0.548
Hayling A	0.373	0.603
Hayling B	0.497	0.434
Brixton	0.684	0.950

The overall Kaiser-Meyer-Olkin (KMO) value was .475 which is slightly below the barely adequate sample level of .5. Lower KMO values can point to the need for larger sample size and is further commented on in the discussion section. Individual KMO values can be seen in Table 2. Even though the Bartlett's Test of sphericity was significant, χ^2 (378) = 1931.922, $p < .01$ and meets the assumption of sphericity, the KMO values suggest that sampling adequacy is below the minimum required level for a factor analysis; therefore the results of the analysis are interpreted with caution.

The PCA extracted 9 components with eigenvalues ranging from 1.087 to 3.973. Table 3 displays the eigenvalues and percentage variance explained before and after rotation for each component. Three different rotations were performed in order to find the best fit for the components. First, an oblique rotation (Oblimin) was performed since components were expected to correlate to some degree. However the component correlation matrix revealed very low correlations among the extracted components. Therefore an orthogonal rotation (which assumes no correlation for extracted components) was performed.

Varimax rotation was the first orthogonal rotation done. However since more than expected components were observed after the PCA, the Varimax rotation did not improve the fit significantly since it aims to disperse loadings in each component and obtain as few variable loadings per component. Therefore, Quartimax rotation which maximizes variable loadings per component was performed. Table 4 displays the rotated component loading with Quartimax. Factor scores were interpreted using the cut-off value of .512, a suggested suitable value for 100 participants (Field, 2005).

Table 3

Percentage Variance Explained by 9 Components Extracted and Associated Eigenvalues

Components	Eigenvalues	%Variance Explained before Rotation	%Variance Explained after Rotation
1	3.973	17.272	11.718
2	2.423	10.536	11.013
3	2.231	9.698	8.688
4	1.874	8.149	8.556
5	1.62	7.042	8.069
6	1.545	6.716	7.566
7	1.297	5.64	6.955
8	1.213	5.274	6.724
9	1.087	4.725	5.761

The first component which explains the 11.718% of the variance is composed of Trails B, Trails B-A and Trails B/A measures. All of the CWI RT measures and Trails A load on the second component and explain 11.013% of the total variance. The third component contains the Digit Backwards, Letter-No. Sequencing and Digit span tests, explaining 8.688% of the total variance. Both of the RT measures of the Zoo Map test load on a fourth component which explains 8.556% of the total variance. The Zoo Map scores do not load on any of the components to a significant degree. The fifth component includes Digit Recall scores and overall Dual- Tasking performance, explaining 8.068% of the total variance. The sixth component contains both the RTs and scores for the Tower test and the Trails A, explaining 7.566% of the total variance. Seventh component contains both measures of the Hayling test (explained 6.955% of variance) and eighth component includes Matrix Reasoning, Vocabulary and Brixton Scores, (6.724%). The final component consists of only Tracking measures explaining 5.761% of total variance. There is reason for concern over possible low factor reliability since the Cronbach's Alpha level was smaller than .7 (23 items; $\alpha = .487$).

Table 4
Factor Loadings for Principal Components Analysis with Quartimax Rotation of Dependent Variables

	Component								
Variables	1	2	3	4	5	6	7	8	9
Trails B/A	**0.955**	-0.094	0.018	0.036	0.019	-0.073	0.052	-0.049	0.064
Trails B-A	**0.909**	0.211	-0.002	0.015	0.032	0.21	0.161	-0.092	-0.016
Trails B	**0.689**	0.387	-0.023	-0.011	0.005	0.421	0.272	-0.119	-0.173
CWI Naming (RT)	0.059	**0.889**	-0.157	0.001	0.011	0.029	0.025	0.049	0.12
CWI Reading (RT)	0.02	**0.815**	0.002	0.023	-0.052	0.153	0.031	-0.246	0.023
CWI Inhibition (RT)	0.373	**0.66**	-0.271	-0.038	0.08	0.074	-0.108	0.163	0.028
Digits Backward	0.013	-0.074	**0.798**	0.105	-0.224	0.066	-0.078	-0.041	0.009
Letter-No Seq.	0.031	-0.019	**0.788**	-0.054	0.048	0.093	-0.12	0.261	0.151
Digit Span	-0.053	-0.292	**0.728**	-0.088	0.153	0.097	0.069	0.017	-0.104
Zoo Map (Overall RT)	-0.03	-0.049	-0.017	**0.944**	-0.092	0.095	0.136	0.018	0.002
Zoo Map (Plan RT)	0.063	0.035	-0.003	**0.931**	-0.041	0.06	0.12	-0.128	-0.049
Digit Recall	0.044	-0.029	-0.043	-0.067	**0.948**	0.091	-0.038	-0.043	-0.152
Dual Task	0.002	0.033	-0.004	-0.077	**0.9**	0.005	0.073	-0.047	0.39
Towers (RT)	0.18	-0.085	0.005	0.165	-0.036	**0.772**	-0.026	0.028	0.086
Towers Score	-0.157	-0.018	0.086	0.004	0.109	**0.602**	0.122	0.352	-0.33
Trails A	-0.223	**0.54**	-0.055	-0.066	-0.019	**0.571**	0.277	-0.079	-0.319
Hayling B	0.039	-0.045	-0.144	0.055	0.014	0.107	**0.747**	0.068	0.046
Hayling A	0.148	0.08	-0.037	0.272	0.049	-0.07	**0.657**	-0.053	0.049
Zoo Map	-0.265	-0.043	-0.215	0.057	0.097	0.289	-0.439	-0.035	-0.102
Matrix Reasoning	0.164	0.017	0.075	0.125	-0.103	0.137	-0.271	**0.704**	0.112
Vocabulary	-0.299	-0.147	0.147	-0.082	0.036	0.094	0.156	**0.645**	0.075
Brixton	0.106	0.007	-0.006	0.198	0.044	0.118	-0.137	**-0.539**	0.241
Tracking	-0.027	0.11	0.063	-0.046	0.11	0.124	0.167	-0.02	**0.868**

Note. Rotation converged in 7 iterations. Significant variable loadings are displayed in bold.
CWI: Colour-Word Interference Test.

Discussion

The aim of the current study was to examine the separability of EFs into five distinct components, and the relationship of these components to measures of intelligence in the framework of the unity and separability of executive abilities. While expecting five separate components, an unexpected nine component solution emerged from the analysis.

Interpretation of the variable loadings is difficult since most of the test variables do not load on their hypothesized EF component. Rather, there is a strong correlation among variables which come from the same test. Considering the nine components, the clearest components are the 1st, 3rd, 5th and 8th components.

The first component includes the Trails B which was hypothesized to tap "Shifting", along with the B-A and B/A measures which were expected to reflect a purer measure of shifting processes. Despite the fact that the Brixton Test did not load on this component, the presence of B-A and B/A measures could suggest that the first component is "Shifting". The Digits Backward, Letter Number Sequencing and Digit Span tests load on the same component as expected. Therefore the third component is believed to display "Updating". Again as expected, the Dual Task performance and the Digit Recall load on separate (5th) component which is likely to reflect "Dual-Tasking". Finally the eighth component is regarded as the "Intelligence" component as it consists of the Matrix Reasoning and the Vocabulary Tests. Surprisingly, the Brixton Spatial Anticipation Test also loads on this component probably due to the rule-attainment aspect of the Brixton test and the Matrix Reasoning test.

Other components are less clear, and more difficult to combine under a common theme. For example Trails A shares the same component with the measures from the Tower Test. This is probably due to the visuospatial characteristics of both tests. For example in Trails A, participants need to scan the page to find the next number in the series. Similarly in the Towers test participants need to keep track of how their current tower relates to the model tower. Moreover both tests involve time pressure. Although time limits were not applied to the Tower test, since the participants were healthy, majority was observed to try to finish each tower as quickly as possible.

There is no reason to believe that the second component reflects "Inhibition" because only the Inhibition RT was thought to reflect this process and not the others RT data from the CWI test. Therefore this component is more likely to reflect the overall characteristic of the test and the Trails A which also loads on this component. One common characteristic of both these test is the time pressure involved during the task, similar to the Towers Test.

The Zoo Map and Hayling Tests also do not provide much information in terms of the hypothesized EFs they were expected to tap on since both tests form separate components. Similarly Tracking loads on the 9th and final component which is likely to reflect the processing speed. However it is interesting that Trails A did not appear on this component since Trails A also has a very strong processing speed aspect.

These nine components could be argued to all reflect 9 separable EFs. However that would be a very rushed decision and such a strong claim should not be solely based on the results of this study. There are a few problems that should be considered when considering the results of the ambiguous components.

First issue to discuss involves the tests chosen to tap each EFs. These are common tests some of which became synonymous with the EF they are hypothesized to tap (Such as Stroop used to measure inhibitory processes, or Towers as a measure of planning processes). However the degree to which these tests reflect their expected executive processes are questionable (Rabbitt, 1997; Burgess, 2005). There is a probability that the tests which were administered in this study to obtain measures of five hypothesized EFs, manifest different processes. The Brixton test is the most obvious example of this. It was expected that Brixton Spatial Anticipation Test would reflect shifting abilities, whereas it is observed to load with the intelligence tests.

Another issue that needs to be addressed is the problem of task impurity: The tests chosen for each EF, are likely to make demands on many cognitive processes other than the executive processes (Rabbitt, 1997) and thus might result in test measures to be uncorrelated among each other. The problem of task impurity could also be more salient for the tests chosen here since they are not designed specifically to tap a certain EF, but rather to display any possible impairment or deficits in a clinical setting.

The extent to which these results can confidently suggest a separable executive system is arguable. Even though some of the expected EFs formed separate components, the low reliability statistics of the factor solution shadow this outcome. Although the "Intelligence" measures were shown not to be an underlying cause behind the test variables, this could be due to the impure nature of the tests used. Therefore it is not possible to directly conclude that Intelligence measures (especially fluid intelligence) is not an underlying factor behind the executive processes.

It is interesting to know if the results of this study would be any different were it analysed using a PA factoring instead of the PCA. Even though both techniques are known to yield similar results, the PA factoring eliminates the error variance associated with every variable, resulting in a purer measure of construct. In addition to this, a larger sample size might help in reducing the problems associated with sample adequacy. Future research should focus on obtaining purer measures of EF and recruiting a larger sample size to overcome the problems encountered in this study and to achieve more meaningful results.

To conclude, this study found evidence for some separability although the results are likely to be influenced by confounding events such as inadequacy of sample size, overall low reliability of the measures and lack of correlations between test variables possibly arising from task impurity. The components that were clear enough to interpret were “Updating”, “Shifting” and “Dual-Tasking” partially supporting the existing literature on the fractionation of executive system (Miyake et al., 2000; Verdejo-Garcia & Perez-Garcia, 2007). It was also observed that overall “Intelligence” component did not share any common loadings with the test variables, apart from the Brixton Test (which may reflect some form of intelligence rather than shifting) suggesting that fluid intelligence is not an underlying element behind the executive processes measured by these neuropsychological tests.

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Appendix

Table A1

Pearson Correlations of 23 Variables.

Variables	Digit Recall %	Tracking %	Dual-Task %	Digit Span	Matrix Reasoning	Vocabulary Test	Digits Backward	Letter-No. Seq.
Digit Recall %	1	-0.124	.793**	0.085	-0.079	-0.019	-0.184	-0.026
Tracking %	-0.124	1	.493**	-0.016	-0.033	0.03	-0.017	0.129
Dual-Task %	.793**	.493**	1	0.075	-0.094	0.005	-0.189	0.053
Digit Span	0.085	-0.016	0.075	1	0.045	0.178	.410**	.446**
Matrix Reasoning	-0.079	-0.033	-0.094	0.045	1	.196*	0.142	0.172
Vocabulary Test	-0.019	0.03	0.005	0.178	.196*	1	0.081	.230*
Digits Backward	-0.184	-0.017	-0.189	.410**	0.142	0.081	1	.493**
Letter-No. Seq.	-0.026	0.129	0.053	.446**	0.172	.230*	.493**	1
Trails A	-0.073	-0.012	-0.061	-.207*	-.201*	-0.041	-0.161	-0.139
Trails B	-0.023	0.053	0	-0.18	-0.105	-.251*	-0.09	-0.081
Trails B-A	0.022	0.089	0.053	-0.118	-0.009	-.272**	-0.033	-0.019
Trails B/A	0.041	0.038	0.037	0	0.048	-.226*	0.037	0.039
CWI Naming (RT)	-0.004	0.12	0.057	-0.395	0.021	-0.078	-0.184	-0.076
CWI Reading (RT)	-0.035	0.075	0.001	-0.174	-0.091	-.272**	-0.047	-0.153
CWI Inhibition (RT)	0.057	0.038	0.067	-.332**	0.062	-0.117	-.286**	-0.133
Towers Score	0.107	-0.192	-0.036	0.158	0.182	.199*	0.071	0.036
Zoo Map Scores	0.016	-0.023	-0.001	-0.114	-0.061	-0.018	-0.086	-0.11
Zoo Map (Overall RT)	-0.173	-0.006	-0.144	-0.076	0.037	-0.004	0.05	-0.057
Zoo Map (Plan RT)	-0.12	-0.012	-0.098	-0.073	-0.073	-0.151	0.059	-0.105
Hayling A	0.004	0.091	0.074	-0.07	-0.083	-0.09	-0.032	-0.074
Hayling B	0.025	0.075	0.053	-0.033	-0.083	0.113	-0.086	-0.167
Brixton	0.055	0.065	0.074	-0.096	-0.159	-0.165	0.057	-0.116

Note. * denotes correlation is significant at the 0.05 level (2-tailed).

** denotes correlation is significant at the 0.01 level (2-tailed).

Variables	Trails A	Trails B	Trails B-A	Trails B/A	CWI Naming (RT)	CWI Reading (RT)	CWI Inhibition (RT)	Towers (RT)	Towers Score
Digit Recall %	-0.073	-0.023	0.022	0.041	-0.004	-0.035	0.057	-0.088	0.107
Tracking %	-0.012	0.053	0.089	0.038	0.12	0.075	0.038	0.087	-0.192
Dual Task %	-0.061	0	0.053	0.037	0.057	0.001	0.067	-0.023	-0.036
Digit Span	-.207*	-0.18	-0.118	0	-.395**	-0.174	-.332**	-0.085	0.158
Matrix Reasoning	-.201*	-0.105	-0.009	0.048	0.021	-0.091	0.062	0.011	0.182
Vocabulary	-0.041	-.251*	-.272**	-.226*	-0.078	-.272**	-0.117	-0.066	.199*
Digits Backwards	-0.161	-0.09	-0.033	0.037	-0.184	-0.047	-.286**	0.004	0.071
Letter-No. Seq.	-0.139	-0.081	-0.019	0.039	-0.076	-0.153	-0.133	0.067	0.036
Trails A	1	.519**	0.109	-.352**	.382**	.290**	.241*	.212*	-0.165
Trails B	.519**	1	.894**	.608**	.347**	.268**	.431**	.290**	-.263**
Trails B-A	0.109	.894**	1	.861**	.240*	0.188	.409**	.235*	-.243*
Trails B/A	-.352**	.608**	.861**	1	0.002	0.015	.242*	0.109	-0.109
CWI Naming (RT)	.382**	.347**	.240*	0.002	1	.671**	.617**	-0.018	-0.102
CWI Reading (RT)	.290**	.268**	0.188	0.015	.671**	1	.389**	-0.079	-0.047
CWI Inhibition (RT)	.241*	.431**	.409**	.242*	.617**	.389**	1	0.089	-0.129
Towers (RT)	.212*	.290**	.235*	0.109	-0.018	-0.079	0.089	1	-.411**
Towers Score	-0.165	-.263**	-.243*	-0.109	-0.102	-0.047	-0.129	-.411**	1
Zoo Map Scores	0.06	-0.128	-0.176	-0.188	0.005	-0.037	-0.072	0.084	-0.035
Zoo Map (Overall RT)	0.024	0.043	0.029	0.019	-0.041	-0.031	-0.09	0.173	-0.061
Zoo Map (Plan RT)	0.05	0.145	0.132	0.11	0.003	0.075	-0.007	0.155	-0.082
Hayling A	0.111	.232*	.223*	0.134	0.109	0.032	0.091	0.071	0.077
Hayling B	0.111	0.19	0.144	0.119	0.096	0.072	-0.068	0.1	-0.031
Brixton	-0.014	0.112	0.139	0.103	0.084	0.059	0.013	0.15	-.281**

Note. * denotes correlation is significant at the 0.05 level (2-tailed).

** denotes correlation is significant at the 0.01 level (2-tailed).

Variables	Zoo Map Scores	Zoo Map (Overall RT)	Zoo Map (Plan RT)	Hayling A	Hayling B	Brixton
Digit Recall %	0.016	-0.173	-0.12	0.004	0.025	0.055
Tracking %	-0.023	-0.006	-0.012	0.091	0.075	0.065
Dual Task %	-0.001	-0.144	-0.098	0.074	0.053	0.074
Digit Span	-0.114	-0.076	-0.073	-0.07	-0.033	-0.096
Matrix Reasoning	-0.061	0.037	-0.073	-0.083	-0.083	-0.159
Vocabulary Test	-0.018	-0.004	-0.151	-0.09	0.113	-0.165
Digits Backward	-0.086	0.05	0.059	-0.032	-0.086	0.057
Letter-No. Seq.	-0.11	-0.057	-0.105	-0.074	-0.167	-0.116
Trails A	0.06	0.024	0.05	0.111	0.111	-0.014
Trails B	-0.128	0.043	0.145	.232*	0.19	0.112
Trails B-A	-0.176	0.029	0.132	.223*	0.144	0.139
Trails B/A	-0.188	0.019	0.11	0.134	0.119	0.103
CWI Naming (RT)	0.005	-0.041	0.003	0.109	0.096	0.084
CWI Reading (RT)	-0.037	-0.031	0.075	0.032	0.072	0.059
CWI Inhibition (RT)	-0.072	-0.09	-0.007	0.091	-0.068	0.013
Towers (RT)	0.084	0.173	0.155	0.071	0.1	0.15
Towers Score	-0.035	-0.061	-0.082	0.077	-0.031	-.281**
Zoo Map Scores	1	-0.006	-0.023	-.222*	-0.118	0.022
Zoo Map (Overall RT)	-0.006	1	.888**	.247*	0.157	0.124
Zoo Map (Plan RT)	-0.023	.888**	1	.251*	0.113	0.13
Hayling A	-.222*	.247*	.251*	1	.322**	0.076
Hayling B	-0.118	0.157	0.113	.322**	1	-0.032
Brixton	0.022	0.124	0.13	0.076	-0.032	1

Note. * denotes correlation is significant at the 0.05 level (2-tailed).

** denotes correlation is significant at the 0.01 level (2-tailed).